DØ Note 6043-CONF

Measurement of the Three-jet Mass Cross Section in $\mathrm{p\bar{p}}$ Collisions at $\sqrt{\mathrm{s}} = 1.96$ TeV

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The differential inclusive three-jet cross section as a function of the invariant three-jet mass ($M_{3\mathrm{jet}}$) is measured in $p\bar{p}$ collisions at $\sqrt{s} = 1.96\,\mathrm{TeV}$ using a data set corresponding to an integrated luminosity of $0.7\,\mathrm{fb}^{-1}$, collected with the DØ detector at the Fermilab Tevatron Collider. The measurement is performed in three rapidity regions ($|y| < 0.8$, $|y| < 1.6$ and $|y| < 2.4$) and in three regions of the third (ordered in p_T) jet transverse momenta ($p_{T3} > 40\,\mathrm{GeV}$, $p_{T3} > 70\,\mathrm{GeV}$, $p_{T3} > 100\,\mathrm{GeV}$) for events with leading jet transverse momentum larger than 150 GeV and well separated jets. NLO QCD calculations are found to be in a reasonable agreement with the measured cross sections.

Preliminary DØ result for Winter 2010 Conferences

I. INTRODUCTION

The dominant part of the total inelastic cross section in $p\bar{p}$ collisions at $\sqrt{s} = 1.96\,\text{TeV}$ is due to the production of jets from parton–parton interactions. Measurements of jet properties can be used to test the predictions of quantum chromodynamics (QCD), to constrain the parton distribution functions (PDFs), and to look for new physics beyond the Standard Model. The measurement of the three-jet cross section can be used to test the next-to-leading order calculations and is sensitive to details of jet clustering algorithm. In this note, we measure the differential inclusive three-jet cross section as a function of the invariant three-jet mass for three hard, well separated jets in three regions of jet rapidities ($|y| < 0.8$, $|y| < 1.6$, $|y| < 2.4$ for all three jets) and in three regions of the third jet ($p_{T3} > 40\,\text{GeV}$, $p_{T3} > 70\,\text{GeV}$ and $p_{T3} > 100\,\text{GeV}$) with leading jet $p_T > 150\,\text{GeV}$.

II. ANALYSIS

This measurement uses data collected with the DØ detector[1] at the Fermilab Tevatron $p\bar{p}$ Collider during 2004–2005. Jets are reconstructed in the DØ liquid–argon and uranium calorimeter using the RunII midpoint cone algorithm[2] with cone radius $R_{\text{cone}} = \sqrt{(\Delta y)^2 + (\Delta\phi)^2} = 0.7$ where $y = 0.5 \ln\left[(E + p_z) / (E - p_z)\right]$ and E is the jet energy, p_z is the jet momentum along the beam axis, and ϕ is the azimuthal angle. The calorimeter covers most of the solid angle. The central calorimeter (CC) covers the pseudorapidity region $|\eta| < 1.1$ ($\eta = -\ln\left[\tan(\theta/2)\right]$ where θ is the angle with respect to the proton beam direction), two end cap calorimeters (EC) extend the coverage up to $|\eta| < 4.2$. The intercryostat region (IC), located between the CC and EC, consists of scintillator based detectors that supplement the coverage of the calorimeter. The calorimeter is segmented into cells of size about 0.1×0.1 in $\eta \times \phi$ plane up to $|\eta| < 3.2$. Radially, the calorimeter is segmented into inner electromagnetic (EM) layer with depth of about 20 radiation lengths followed by hadronic (HAD) layers of depth of about 7 nuclear interaction lenghts which is deep enough to contain about 98% of all the collision energy.

The event selection follows closely those used in our recent measurements of inclusive jet and dijet distributions[3–5]. Events must contain at least three reconstructed jets and are required to satisfy jet trigger requirements with a minimum transverse momentum threshold on the leading jet. Trigger efficiencies are studied by comparing triggers with higher thresholds to triggers with lower thresholds in regions where the latter trigger is 100% efficient. This analysis uses only high p_{T} inclusive jet triggers which select events with leading jet transverse momentum larger than 150 GeV. Events are also required to pass data quality and jet identification quality (jetID) criteria for each of the leading three jets in an event. The third jet transverse momentum must be larger than $40\,\text{GeV}$. Any pair ij of the three jets are required to be well separated in the $y \times \phi$ space by $R_{ij} = \sqrt{(\Delta y_{ij})^2 + (\Delta\phi_{ij})^2} = 2R_{\text{cone}} = 1.4$. The position of the $p\bar{p}$ interaction is determined from the tracks reconstructed in the tracking system consisting of silicon mistrostrip detectors and scintillating fibers inside a solenoidal magnetic field. The position of the primary $p\bar{p}$ interaction vertex along the beam line is required to be within 50 cm of the detector center. The primary vertex is required to have at least three tracks pointing to it. To reduce a contribution of cosmic ray events, a requirement on the missing transverse energy ($\not{E}_T$) in an event is used. Events are rejected if $\not{E}_T/p_T^{\text{lead}} > 0.7$ if $p_T^{\text{lead}} < 100\,\text{GeV}$ or $\not{E}_T/p_T^{\text{lead}} > 0.5$ if $p_T^{\text{lead}} > 100\,\text{GeV}$, where p_T^{lead} is the transverse momentum of the highest p_T jet (no jet energy scale correction is applied in this requirement), are rejected. The efficiency of the missing transverse energy requirement was studied on the inclusive jet sample and the requirement was found to be almost fully efficient[3].

A jet energy scale (JES) correction is applied to jet four momentum as the measured four momentum of a jet is not the same as of a jet entering the calorimeter due to the response of the calorimeter, energy showering in and out of the cone and additional energy from detector noise, event pile-up and multiple $p\bar{p}$ interactions. The JES correction is determined using the p_T imbalance in γ + jet and dijet events. The additional energy from pile-up and multiple interaction is determined from a minimum bias sample. The JES corrections are of the order of 50% for a jet energy of 50 GeV and 20% for a jet energy of 400 GeV. The corrected four-momenta are used for the transverse momenta and rapidity requirements and for the determination of the three-jet mass.

Because of the falling three-jet mass spectrum, the measured spectrum is systematically shifted towards higher values (as compared with the true distribution) mainly due to jet transverse momentum resolution. The transverse momentum resolution is about 15% at 40 GeV decreasing to less than 10% at 400 GeV (these resolutions are slightly degraded in the intercryostat region between the central and end cap calorimeters). The mass spectrum in data is corrected to particle level [6] using a parameterized simulation of the detector with energy and angular resolutions obtained from the data. The events generated with the SHERPA[7] Monte Carlo generator with MSTW2008LO PDFs[8] are used as an input to the parameterized simulation. The simulated events generated with SHERPA are reweighted to match the measured $p_T, |y|$ and other distributions in the data. The parameterized simulation is then used to correct the three-jet cross section for various detector effects including angular resolutions and biases, misvertexing, jetID efficiency and the difference on jet energies due to muon and neutrinos which is not considered in the JES. The correction (C_{unsmear} in Eq. 1) is defined as the ratio between the smeared and the original particle level distributions in $M_{3\text{jet}}$. Due to the resolution, the reconstructed event could end up in a different bin that it was originally generated. The bin sizes of the three-jet mass bins are chosen to be about twice the mass resolution and to have efficiencies and purities of $\geq 40\%$, where efficiency is defined as the ratio of Monte Carlo events generated and reconstructed in a given bin divided by the total number of events generated in that bin, purity is defined as the ratio of Monte Carlo events generated and recontructed in a given mass bin divided by the total number of event reconstructed in that bin. The overall detector corrections vary from about 1.0 at 400 GeV to 1.1 at 1100 GeV in the $|y| < 0.8$ region and between 0.89 at 400 GeV to 0.96 at 1000 GeV in the $|y| < 2.4$ region.

III. RESULT

The three-jet mass cross section is calculated using Eq. (1).

$$\frac{\mathrm{d}\sigma}{\mathrm{d}M_{3\text{jet}}} = \frac{1}{L \cdot \Delta M_{3\text{jet}}} \cdot \left(\sum_{i=1}^{N_{\text{evt}}} \frac{1}{\epsilon_{\text{v}}^{i}} \right) \cdot C_{\text{unsmear}} \qquad (1)$$

where L is the integrated luminosity, ϵ_{v}^{i} is the vertex efficiency (applied on event by event basis), $\Delta M_{3\text{jet}}$ is the mass bin width, N_{evt} is the number of events in a given $M_{3\text{jet}}$ bin, and C_{unsmear} is the correction factor for the detector effects. The three-jet mass spectra are shown in Figs. 1 and 2. The data are compared to the NLO predictions calculated in NLOJET++[9] program with MSTW2008NLO PDFs. The NLO prediction is corrected for hadronization and underlying event effects, with correction varied in the range from -3% to 6%, obtained from PYTHIA[10] simulations using tune QW[11]. The renormalization and factorization scales are set to $\mu = \mu_r = \mu_f = 1/3(p_T^1 + p_T^2 + p_T^3)$ where $p_T^{1,2,3}$ are the transverse momenta of leading, second and third jets. The effect of variation of the scales to 2μ and to 0.5μ is shown in the data to theory ratio in Fig. 3.

The systematic uncertainties of the measurement are dominated by the uncertainties from the jet energy scale, which range from 10% to 15% in the $|y| < 0.8$ region to 10% to 30% in the $|y| < 2.4$ region. The second largest uncertainty comes from transverse momentum resolution which ranges from 1% to 5%. The integrated luminosity has an uncertainty of 6.1% which is completely correlated across the three-jet mass bins. The remaining systematic uncertainty of 3.5%, which is caused by the vertex requirements, jetID efficiency, η resolution and bias, ϕ resolutions and Monte Carlo model dependence, is calculated using the parameterized detector simulation. Trigger efficiency uncertainty of 2% is added to the total systematic uncertainty. The statistical uncertainty ranges from 2% at 0.45 TeV to 21% at 0.95 TeV in the $|y| < 0.8$, from 0.7% at 0.45 to 20% at 1.15 TeV in the $|y| < 1.6$ and from 0.6% at 0.45 TeV to 10% at 1.15 TeV in the $|y| < 2.4$ region. In the third jet transverse momentum regions, the statistical uncertainty ranges from 1% at 0.45 TeV to 12% at 1.15 TeV for $p_{T3} > 70\,\text{GeV}$ region and from 2% at 0.45 TeV to 18% at 1.1 TeV for $p_{T3} > 100\,\text{GeV}$ region.

IV. SUMMARY

In summary, we have presented the first measurement of the inclusive three-jet cross section in hadron–hadron collisions at a center of mass of $\sqrt{s} = 1.96\,\text{TeV}$. The inclusive three-jet cross section is presented in three regions of $|y|$ and three regions of third jet p_T as a function of the invariant three-jet mass. The data are reasonably well described by the next-to-leading order calculation done with NLOJET++ and the MSTW2008NLO PDFs.

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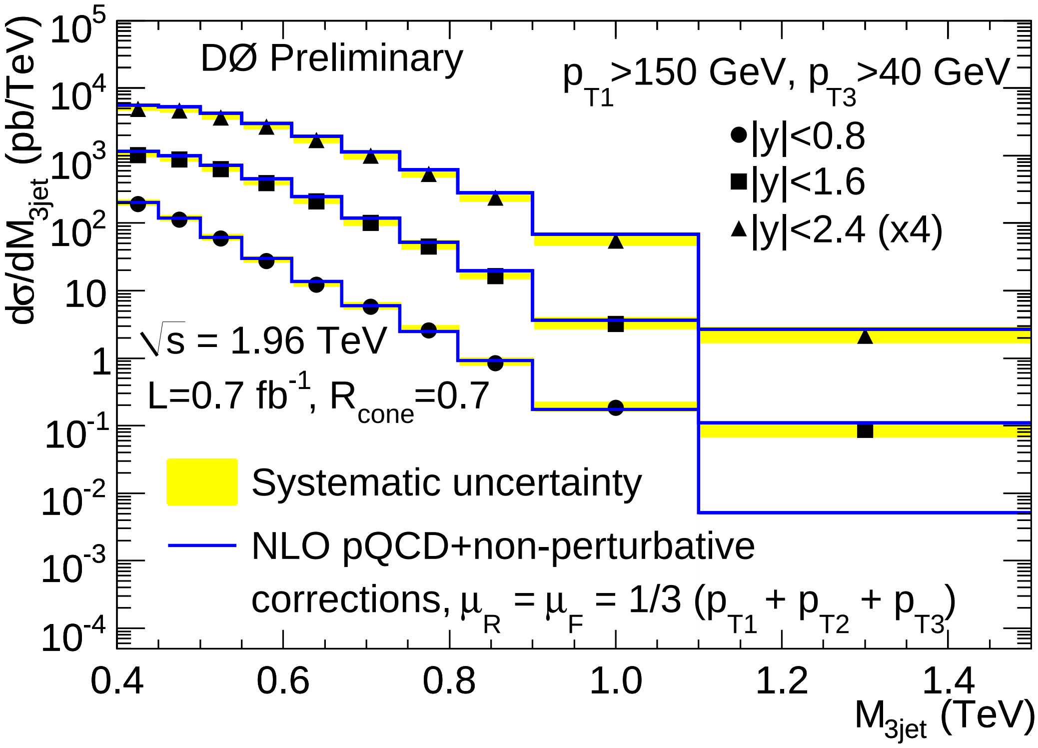

FIG. 1: Three-jet mass cross section in regions of jet rapidities. The dataset corresponds to an integrated luminosity of 0.7 fb^{-1}. The $|y| < 2.4$ region is scaled by a factor of 4 for readability. Systematic uncertainty is shown by shaded band. Full lines correspond to the NLO calculations with NLOJET++ and MSTW2008 PDFs. No events are found in the highest $M_{3\mathrm{jet}}$ bin in $|y| < 0.8$ region.

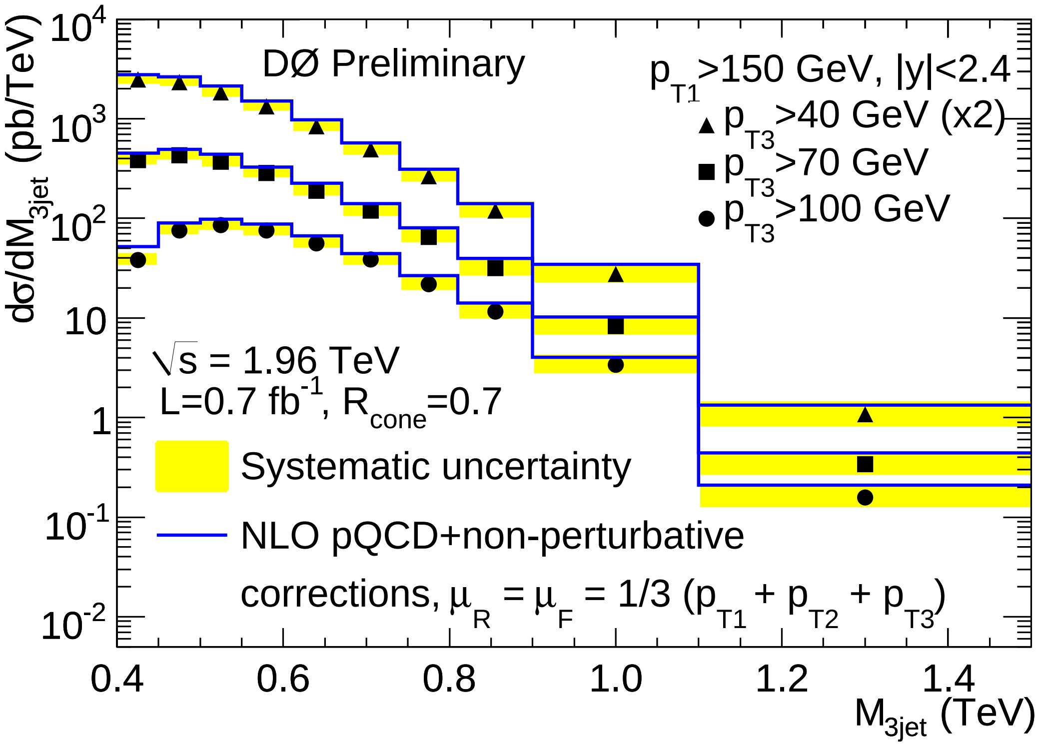

FIG. 2: Three-jet mass cross section in regions of the third jet transverse momenta. The dataset corresponds to an integrated luminosity of 0.7 fb^{-1}. The $p_{T3} > 40$ GeV region is scaled by a factor of 2 for readability. Systematic uncertainty in all three-jet mass bins is shown by shaded band. Full lines correspond to the NLO calculations with NLOJET++ and MSTW2008 PDFs.

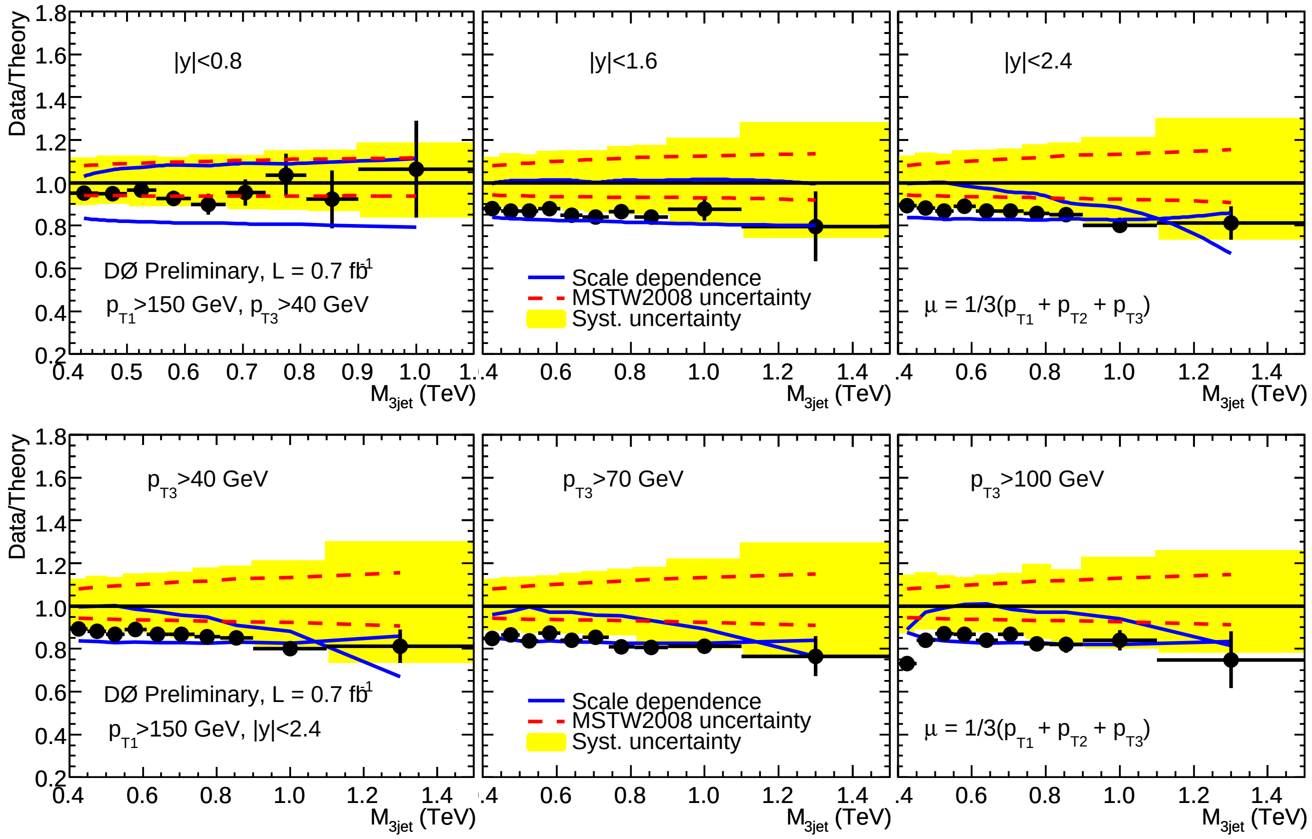

FIG. 3: Data to theory ratio in three regions of jet rapidites (top) and three regions of the third jet transverse momenta (bottom). The total systematic uncertainty is shown by a shaded band centered around the theory. The PDF uncertainty comes from the 20 MSTW2008NLO eigenvectors. The scale uncertainty is determined by varying the scale up and down by a factor of 2.

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